

Wind Erosion Abrasion: Effects of Aggregate Moisture

L. J. Hagen, E. L. Skidmore, J. B. Layton

ASSOC. MEMBER
ASAE

ABSTRACT

AFTER rain showers, wind erodible-size particles on the surface dry rapidly and often begin abrading the surface aggregates and crust while the latter are still moist. The objectives of this investigation were to measure the abrasive loss rates of moist aggregates and develop prediction equations of the loss rates that would be useful in field studies as well as in development of complex wind erosion models. Accordingly, soil samples were obtained from four soils ranging from a sandy loam to a silty clay loam. Forty aggregates, 4, to 6 cm in diameter, were selected from each soil and then further subdivided by establishing four moisture levels with 10 aggregates at each level. Each aggregate was abraded in an enclosed chamber using a calibrated sandblasting nozzle. A stability test was also conducted on air-dried subsamples of each soil. In this test, 1.3 to 1.9 cm diameter aggregates were crushed to a fixed end point and the work done per unit mass (J/Kg) was measured.

Test results showed that the slope of a regression line for the abrasion loss rate versus normalized moisture content varied in a systematic manner, as dry aggregate stability ranged from low to high. Thus, it was possible to develop a simple estimating equation to predict abrasion loss rate as a function of average dry aggregate crushing energy and aggregate moisture content.

INTRODUCTION

The United States Department of Agriculture has initiated a major effort to replace the current wind and water erosion prediction equations with computer models that simulate erosion and other related phenomenon (Laflen et al., 1988). In simulating wind erosion, three major processes have been identified. At each point on the surface, wind erosion can be represented as a net soil gain caused by trapping (deposition) or a net soil loss caused by either emission of loose, erodible-size aggregates or abrasion of large aggregates or crust (Hagen and Armbrust, 1985). The focus of this study is on aggregate abrasion loss rates as influenced by soil moisture.

One role of moisture in the wind erosion cycle can be described as follows: rain often carries some of the finely dispersed, water-soluble cementing materials downward, leaving coarse particles such as sand and water-stable aggregates at the top. Chepil (1956) studied the effect of moisture on erosion of these coarse particles by measuring soil loss rates from wind tunnel trays filled with all erodible particles. He found that the erosion rate began to decrease whenever soil moisture exceeded 1/3 the moisture content at the -1.5 MPa matric potential. As moisture increased to the moisture content at -1.5 MPa, soil loss decreased to nearly zero at wind speeds of 14 m/s. Johnson (1965) also reported the effects of both sand moisture levels and air humidity on threshold wind speeds of sand. Thus, the increased shearing stresses necessary to detach erodible-size particles with adsorbed water films are relatively well understood.

However, erodible-size particles on the surface dry rapidly and often begin abrading the surface clods and crust while the latter are still moist. This abrading action tends to hasten drying of the surface, build the supply of abrading particles, and break down both the surface clods and the crust. Chepil and Woodruff (1963) described the abrasion of moist soils as follows: "Small showers often tend to smooth the soil surface, to loosen some of the surface particles, and if the field is large, to accelerate rather than alleviate soil movement by wind." The major factors that control the abrasion rates of dry soil aggregates, such as abrader impact angle and velocity as well as target aggregate stability, have been investigated (Hagen, 1984). When used as abrader, washed sand caused slightly more abrasion loss than soil particles sieved from the target aggregate soils. In general, abrasion loss was proportional to the kinetic energy of the impacting particles, and impact angles of 15 deg caused more abrasion loss than larger impact angles. But, the response of wet aggregates to abrasion has not been studied. The objective of this investigation was to measure the abrasive loss rates of moist aggregates and develop prediction equations of the loss rates that would be useful in field studies as well as in development of wind erosion models.

EXPERIMENTAL PROCEDURE

Soil samples for abrasion resistance testing were obtained from the Ap horizon of Carr (Typic Udifluent), Haynie (Mollic Udifluent), Reading (Typic Argiudoll), and Smolan (Pachic Argiustoll) soils. The soils were air-dried in the laboratory, and subsamples were oven-dried at 105 °C to determine average air-dried moisture content. Particle-size distribution was determined for each soil using the pipet method (Gee and Bauder, 1986). Soil organic matter content was

Article was submitted for publication in December, 1987; reviewed and approved for publication by the Soil and Water Division of ASAE in March, 1988.

Contribution from the U.S. Dept. of Agriculture, Agricultural Research Service, in cooperation with Dept. of Agronomy, Kansas Agricultural Experiment Station Contribution Number 88-159-J.

The authors are: L. J. HAGEN, Agricultural Engineer, USDA-ARS; E. L. SKIDMORE, Soil Scientist, USDA-ARS; and J. B. LAYTON, Research Assistant, Dept. of Agronomy, Kansas State University, Manhattan.

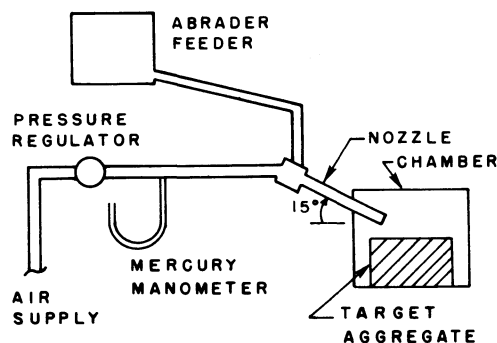


Fig. 1—Schematic diagram of abrasion test apparatus.

determined by the Kansas State University Soil Testing Laboratory using a recommended test (Schulte, 1982).

Forty aggregates, 4 to 6 cm in diameter, were selected from each soil as targets for the abrasion tests. One side of each aggregate was leveled to serve as the abrader impact surface. Each group of 40 aggregates was further subdivided by establishing four moisture levels with 10 aggregates at each level. Moisture levels were established by placing each aggregate on filter paper in a container and adding a predetermined amount of distilled water to the paper. The aggregates were then allowed to equilibrate for 48 h in the closed container. Soil aggregates were reweighed before abrasion, and their individual moisture content was calculated. Moisture contents generally ranged from 7.5 to 50% of the moisture retained by soils at the -0.033 MPa matric potential (field capacity).

Each aggregate was placed in a small, enclosed chamber and abraded until several grams were removed from the target aggregate. The abrasion was accomplished using a commercial sandblasting nozzle fed at a rate of 1.67 g/s with washed, quartz river sand 0.29 to 0.42 mm in diameter (Fig. 1). Air pressure to the nozzle was regulated to maintain a constant abrader particle velocity of 4.4 m/s at an impact angle of 15° . The abraded aggregates were weighed and then subjected to a drop-shatter test to determine their stability. Shattered aggregates were sieved to determine the new surface area created by the drop energy input. Aggregate stability was calculated as energy per unit of new surface area (J/m^2) as described by Hagen (1984). Finally, the shattered aggregates were oven-dried at $105^\circ C$ and reweighed to determine soil lost during abrasion.

A second stability test was also conducted on air-dried subsamples of each of the four soils. In this test, aggregates between 1.3 and 1.9 cm were obtained by sieving. Energy to crush these small aggregates was then measured using two parallel plates in the apparatus described by Boyd et al. (1983). Aggregates were crushed to approximately the same end point, so no more than 5% of the fragments remained on a 6.35 mm screen and at least 5% were held on a 3.36 mm screen. The work done per unit mass in the crushing process (J/kg) was measured as described by Skidmore and Powers (1982).

RESULTS AND DISCUSSION

Analyses of the primary size distributions of the test soils showed that their textures ranged from a sandy loam to a silty clay loam (Table 1). The organic matter

TABLE 1. COMPOSITION OF TESTED SOILS

Soil series	Sand*	Silt*	Clay*	Organic matter
	%			
Carr sandy loam	69.9	24.1	6.0	1.07
Haynie loam	42.1	46.0	11.9	1.90
Reading silt loam	7.9	67.6	24.5	2.33
Smolan silty clay loam	7.3	58.2	34.5	1.93

*Sand, > 0.05 mm; silt, $0.05 - 0.02$ mm; clay < 0.02 mm diameter

contents were typical for tilled soils in the area and ranged from 1.07 to 2.33% . Abrasion loss rates varied widely among the soils (Fig. 2). Air-dried aggregates from the relatively tough Smolan silty clay loam had an average abrasion loss rate (W) of 0.7 g/kg of abrader, whereas the loss rate of air-dried Carr sandy loam aggregates was 100 times that of the Smolan aggregates.

Linear regression was used to relate $\ln(W)$ to $\ln(S_a)$, where \ln is log to the base e and S_a is the drop-shatter stability (J/m^2). For aggregates at all moisture levels, the result was

$$\ln(W) = 3.474 - 1.14 \ln(S_a), R^2 = 0.58 \dots [1]$$

Although the drop-shatter test alone provided an indication of the abrasion loss rate at the various moisture levels, more than 40% of the variance was still unexplained. Thus, additional variables appeared necessary to closely predict abrasion rates of wet aggregates. By adding soil texture and moisture variables to equation [1], it was possible to obtain R^2 values exceeding 0.90 . However, such a prediction equation would be inconvenient to use in practice because measurements or estimates of aggregate stability at several moisture levels would be required.

A second approach to predicting moist aggregate abrasion rates is to use only the dry aggregate stability in the prediction equations. In another study, crushing energy (J/kg) was found to be a slightly better indicator of dry aggregate abrasion rate than drop-shatter stability (Skidmore et al., 1988). Linear regression analysis of the abrasion loss rate of air-dried aggregates alone gave

$$\ln(W) = 5.06 - 0.064 (CE), R^2 = 0.94 \dots [2]$$

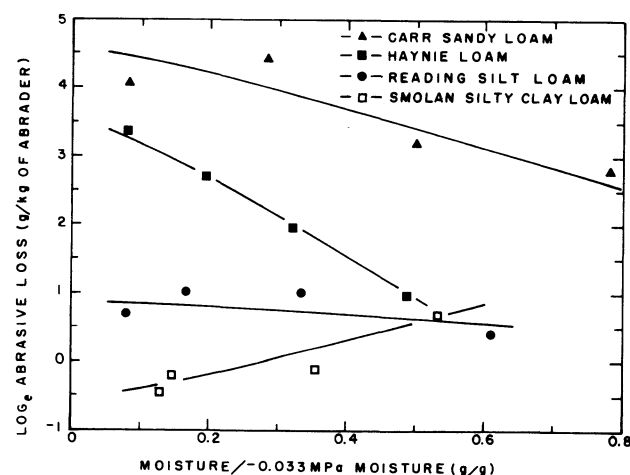


Fig. 2—Average \ln abrasion loss rate as a function of average normalized aggregate moisture content.

TABLE 2. MEASURED AND PREDICTED SOIL PROPERTIES

Soil series	Average crushing energy, J/kg	Predicted bulk density, Mg/m ³	Predicted -0.033 MPa moisture, g/g
Carr sandy loam	14.6	1.42	0.12
Haynie loam	29.3	1.27	0.22
Reading silt loam	67.8	1.28	0.31
Smolan silty clay loam	87.9	1.31	0.32

This result suggests that measurements of crushing energy (CE) can be used to adequately predict $\ln(W)$ of dry aggregates. Hence, average measured CE was adopted as an independent indicator of air-dried aggregate abrasion loss rate for each soil (Table 2). For researchers sampling a large number of field soils, measurements of CEs are much less time consuming than measuring abrasion loss rates.

To aid in describing aggregate moisture variables, a moisture scaling factor at -0.033 MPa (= field capacity) was also computed for each soil. The moisture content at the -0.033 MPa matric potential (M_r) was estimated using the prediction equation developed by Rawls et al. (1982) where

$$M_r(\text{cm}^3/\text{cm}^3) = 0.2576 - 0.002 (\% \text{ sand}) + 0.0036 (\% \text{ clay}) + 0.0299 (\% \text{ organic matter}) \dots \dots \dots [3]$$

Aggregate bulk densities were estimated using the prediction graph of Rawls (1983). Finally, using the predicted bulk densities, M_r was converted to a mass basis (Table 2).

Addition of moisture to the aggregates affected $\ln(W)$ in a complex manner. Examination of the average $\ln(W)$ at average normalized moisture levels (M/M_r) showed a strong interaction between moisture and dry aggregate stability (Fig. 2). For all soils, except Smolan, the abrasion loss rate decreased as aggregate moisture increased. Adding moisture to the Smolan aggregates increased their abrasion loss rates. The primary particles of the Carr and Haynie soils were weakly cemented, as manifested by their low dry aggregate stability. The cohesion of the adsorbed water increased their resistance to abrasion. Whereas, the strong bonding of the Smolan soil, manifested by high dry aggregate stability, was weakened by adding water, thus, decreasing resistance to abrasion. The decrease of $\ln(W)$ of aggregates as moisture increased was larger for the Haynie loam than the response of soils with either weaker or stronger aggregates. In other studies, soil strength of compacted soils has been observed to increase with moisture content until moisture content reached about 55% of the liquid limit and then drop sharply (Ohu et al., 1986). Thus, it is not surprising that abrasion loss rates usually decreased as soil moisture increased for moisture levels well below field capacity.

Using only CE and normalized moisture (M/M_r), the following non-linear regression equation was selected for its simplicity and high degree of explained variance.

$$\ln(W) = 5.625 - 0.0706 (\text{CE}) + 1.072 (S) (M/M_r)^{1.2} , \\ R^2 = 0.92 \dots \dots \dots [4]$$

where the slope term, S , depends on the air-dry CE and fits the function

$$S = 4.35 \cos (5.464 - 0.062 (\text{CE})) - 1.85 \dots \dots \dots [5]$$

The solid lines in Fig. 2 were generated for each soil using prediction equation [4].

The relationship between the predicted values and the measured data points are further illustrated in Fig. 3. Although one could improve the R^2 value of equation [4] by removing a few outlying data points, there do not appear to be obvious trends in the deviations from the predicted values. Plots of the residuals between measured and predicted values against several independent variables also did not reveal other significant trends in the data. Thus, crushing energy and normalized soil moisture appear to be an adequate

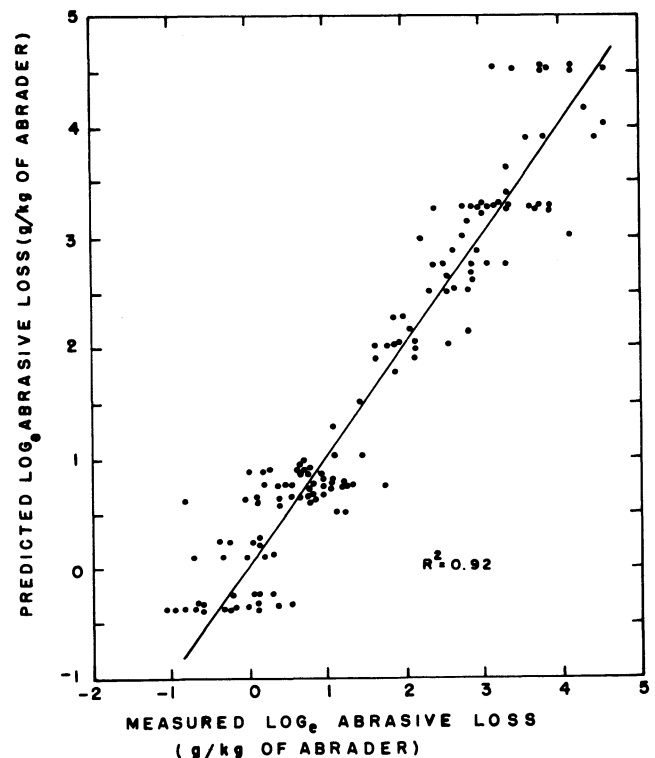


Fig. 3—Predicted \ln abrasion loss rate data as a function of measured loss rates. Solid line is 1:1 line.

number of independent variables to predict the \ln of the abrasion loss rate.

CONCLUSIONS

Data from the three soils with the weakest aggregates showed that abrasion loss rates decreased as target aggregate water content increased. Because soils with weak aggregates are generally most susceptible to wind erosion, the addition of moisture to their aggregates should tend to reduce wind erosion. Indeed, increasing aggregate moisture of Carr sandy loam and Haynie loam soils to 50% of their estimated moisture contents at the -0.033 MPa matric potential reduced their abrasion loss rates to 45 and 10%, respectively, of their air-dry loss rates. Hence, when rain showers increase field wind erodibility, other mechanisms must act to offset the increased resistance of the aggregates to abrasion. Obvious possibilities include loss of abrader trapping capacity because of surface smoothing, replacement of surface clods by weak crusts, and increases in the amount of loose abrader on the surface.

The slope of abrasion loss rate versus moisture data varied in a systematic manner, as dry aggregate stability ranged from low to high. Thus, it is possible to develop simple estimating equations to predict \ln of abrasion loss rate as a function of average dry aggregate crushing energy and aggregate moisture content. These results should be useful in designing field sampling studies, as well as in developing complex models of the wind erosion process.

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